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PRELIMINARY INVESTIGATION of the POTENTIAL IMPACT of the REWATERING of MOLYCORP'S DEEPER UNDERGROUND MINE on the RED RIVER near QUESTA, NEW MEXICO

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TABLE OF CONTENTS

LIST OF APPENDICES

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LIST OF FIGURES

1.0 INTRODUCTION

The Molycorp/Questa molybdenum mine is located on the western slope of the Taos Range of the Sangre de Cristo Mountains, Taos County in north-central New Mexico (Figure 1). State Highway 38 runs along the north side of the Red River and connects the mine and mill area with the Town of Red River (6 miles to the east) and the Town of Questa (6 miles to the west).

Mining History

The Questa Molybdenum mine was initially developed by Molycorp in the 1920's (Schilling, 1956). This underground mining operation consisted of the development of numerous adits and drifts between the elevation of 8864 feet (Old Glory hole) and 7764 feet at the deepest level. The mine portals were along Sulphur Gulch, an intermittent tributary to the Red River. An adit (Moly tunnel) extended south from about the 8000-foot level to an elevation of 7969 feet near the Red River. The elevation of the Red River segment opposite the mined area ranges from about 7700 feet to 7950 feet.

In the late 1950's, the underground mining was replaced by an open-pit operation which removed much of the upper part of the old underground workings. A deeper-level mineralized zone was identified in 1975, and underground mining by the block-caving method began. The deepest level in the new workings is the Haulage level (elevation 7120 feet), above which is the Grizzly level and the Undercut level (elevation 7310 feet). The service shaft (No. 1 shaft) is located about 800 feet north of the Red River and extends from a surface elevation of 8090 feet to the Haulage level. Shaft No. 2 lies north of No. 1 and extends from a surface elevation of 8270 feet to the Haulage level. A caved area developed above the new workings along Goat Hill Gulch. The caved zone extends from the surface (approximate elevation of 7975 feet) to a depth of approximately 795 feet (elevation of 7180 feet).

The mine is currently on standby status until economic conditions improve for the molybdenum market. With an increase in demand/price for molybdenum, the mine will be dewatered and operations resumed.

Purpose of This Investigation

Pre-mine measurements for water-level elevations (from which flow direction and hydraulic gradient could be measured) are unknown for the area, as are most of the other hydrogeological parameters (such as hydraulic conductivity for the fractured and mineralized bedrock and pre-mine ground-water chemistry). Springs close to the elevation of the Red River and accretionary studies along the river (pre- and post-deep underground mining) indicate that the river is a gaining stream and that ground water supplies some of the flow. The primary questions to be addressed in this study focus on any potential impact of the mine waters, during the rewatering phase, on the Red River.

Natural recharge (through the mine workings and the fractured bedrock) will cause the mine's water-level to rise until it reaches about the natural (pre-mine) water table that extended across the area north of the Red River. An early question to be considered is the probable configuration of this pre-mine water-table surface. Some of the recharge is being captured by a seepage barrier system located near the toes of the upper mine waste dumps and is being drained into the underground workings through the caved area in Goat Hill Gulch. Given the present rate of recharge into the mine opening, the questions that must be addressed are:

- What will the post-mine water table look like (in terms of configuration, elevation, and gradient)?
- When will this post-mine water table configuration be reached?
- What are the critical levels in the underground mined area at which flow might move toward the river?
- How long would it take mine water to discharge to the Red River?
- What would be the impact of the mine water on the chemistry of the river?
- Are there critical elevations for the rising water level at which measures should be taken to prevent mine water from reaching the river?
- What measures might be undertaken to control or prevent the flow of mine waters to the river?

2.0 GEOLOGY

2.1 General Geologic Setting

The major sources of geological data for the Questa Mine area are Schilling (1956), Rehrig (1969), Lipman (1981), Bookstrom (1981) and numerous unpublished maps, cross-sections, and reports by Molycorp geologists. A common thread to all of these geological studies is that the mineralization at Questa was related to Tertiary magnetism and hydrothermal solutions focused along an east- to northeast-trending structural zone. This structural zone is variously interpreted as part of a graben (Schilling, 1956); as a zone of intense faulting (called the *Red River Structural Zone* by Rehrig, 1969); and the southern part of the outer ring fracture zone that formed the outer wall of the Questa caldera (Lipmann, 1981; Bookstrome, 1981).

The development of the caldera and the associated volcanic and intrusive rocks was a late Oligocene to Middle Miocene event (27.2 million years to 22 million years before present) that overlapped in time and space with the regional rifting associated with the Rio Grande Rift System. The range-bounding high-angle fault along the west side of the Sangre de Cristo Mountains (about 5 miles west of the mine) is related to regional extension across the Rio Grande Rift and the uplift of the range in Mid-Tertiary time. At least the later movements along this range-front fault are younger than the caldera structure because the outer ring fracture zone is truncated by the range-front fault.

2.2 Rock Units

The oldest rock units exposed in the vicinity of the mine are Precambrian amphibolites, quartz-biotite schists, metaquartzites, granite gneisses, and intrusive quartz monzonites. These units are overlain by an Early Tertiary conglomerate and sandstone unit followed by a complex sequence of Oligocene and Miocene rhyolitic to quartz latitic ashflow tuffs, breccias, and lava flows and a sequence of basalt/andesite lava flows. These volcanics are intruded by a number of dikes and small stocks or plutons that range widely in composition (quartz latite, rhyodacite, rhyolite, granite porphyry, and aplite). At the Questa mine, most of the molybdenum mineralization is found in the outer parts of the Mine Aplite (22 million years before present) and adjacent volcanic units.

2.3 Structure

Geological maps of the Questa mine area (Figure 2) all show a northeast- to east-trending structural zone along which intrusions of granitic rock and mineralization have occurred. This zone more or less parallels the Red River in the vicinity of the mine, but swings to the southwest, away from the river, farther to the west. The structural zone is believed to be the southern part of the outer ring fracture zone (outer wall or rim) for the Questa Caldera. The zone is characterized by a swarm of east-trending dikes, elongated intrusions, and mineral veins that were emplaced in fractures developed parallel to the caldera rim.

South of the structural zone, northeast- and northwest-trending high-angle faults extend throughout the Precambrian block (Precambrian rocks and some pre-caldera volcanic rocks). Some of these faults are truncated by the caldera wall. North of the structural zone, the geology is more complex. Fault-bound blocks of Precambrian rocks, pre-caldera volcanics, and younger caldera-related volcanics occur throughout the area. These structural blocks and the outer fracture zone along the caldera wall became the plumbing system through which granites intruded (e.g., Mine Aplite) and the later mineralizing hydrothermal waters migrated.

A variety of fractures developed throughout the caldera block. These include:

- high-angle joints (called sheeting in the aplite) and fracture cleavage;
- contact conformable fractures between the intrusions and the volcanic units;
- high-angle northeast-, north-, and northwest-trending faults;
- low-angle faults both within the Mine Aplite (west-dipping) and as structural contacts between various Tertiary units.

The low-angle faults are illustrated on cross-sections located on Figure 3 and shown on Figures 4 and 5. These are probably related to listric (concave-up fault planes), normal faults developed along the caldera boundary, and/or large slide blocks derived from the walls of the caldera. Some of the northerly-trending high-angle faults extend to the caldera boundary near the Red River truncating the easterly structures.

2.4 Mineralization

The mineral deposit consists of quartz/molybdenite (molybdenum sulphide) vein fillings in east- to northeast-striking, nearly vertical fractures in the Mine Aplite and in the immediately adjacent andesitic flow rocks intruded by the Aplite. Pyrite (iron sulphide) is fairly abundant in the quartz veins (with or without molybdenite) and in the clay gouges that fill some of the fault zones. Calcite, fluorite, and biotite are commonly associated with the vein minerals. The major alteration mineral in the volcanics outside of the veins is chlorite. Field photographs by Rehrig (1969) indicate that many fractures and small faults are barren of mineralization.

Schilling (1956) described intense zones of alteration associated with hydrothermal pipes (i.e., steeply inclined breccia structures) that probably formed at fault/fracture intersections in the volcanic rocks overlying the intrusion. The alteration minerals in these pipes consist of pyrite, chalcopyrite, quartz, kaolinite, sericite, and carbonates. Subsequent descending oxidizing ground-waters reacted with the pyrite and carbonate minerals to form limonite (iron oxide), jarosite (hydrous iron/potassium sulphate), and gypsum (hydrated calcium sulfate) creating the yellow- and red-colored hydrothermal scars common throughout the area. Schilling (1956) reported that iron-enriched mine drainage waters precipitated limonite near the portal to Z tunnel (old underground workings) and that pre-mine alluvial deposits cemented by limonite occur in the upper Sulphur Gulch drainage above the older workings. This indicates that the natural oxidation processes of the past continue today in the mine area.

3.0 HYDROGEOLOGY

3.1 Hydrogeological Units

The ground-water hydrology of a region is best discussed by grouping the numerous geologic formations into units of hydrogeologic significance. A basic division universally used is aquifer and aquitard. Various geologic units are then assigned to one of these categories, commonly in some kind of stratigraphic and/or structural relationship (e.g., upper volcanic aquifer or lower crystalline aquitard, etc.). Where possible, groupings are based on rock and structural descriptions of the rocks and on aquifer tests or other tests for hydrologic characteristics. Lacking site-specific tests, hydrogeologic properties may be estimated from values published on studies of similar rocks elsewhere. At the Questa Mine area, the identified hydrogeologic units are:

- Precambrian Aquitard,
- Tertiary Aquifer, and
- Hydrothermal Alteration ("Scar") Aquitard.

__Precambrian/Tertiary__: The Precambrian metamorphic and intrusive rocks and the stock-like Tertiary intrusives (Mine Aplite) form a hydrogeological basement or a regional aquitard analogous to the regional lower clastic (Precambrian/Cambrian quartzites) aquitard identified by Winograd and Thordarson (1975) in central and eastern Nevada. While shallow fracture systems (and in some cases, major through-going faults) allow for some movement of ground water, these rocks are characterized by low hydraulic conductivity and serve as barriers to deep circulation of ground water. Schilling (1956), in characterizing the vertical fracture system in the Mine Aplite, noted that these fractures pinch out downward into the main intrusive mass. These fractures (along with numerous small faults) are also mineralized in the ring fracture fault zone.

__Tertiary Aquifer__: The Tertiary volcanics and sedimentary rock units are highly fractured and faulted throughout the caldera block north of the river. The major structural features are high-angle northwest-, north- and northeast-trending faults and low-angle faults, either parallel to the intrusive/volcanic contact (contact conformable fractures) or along unit contacts. Joints related to some combination of tectonic and volcanic processes are also present in the volcanic units. Although mineralization and/or clay gouge along faults has sealed some of the fractures, not all are sealed and fracture flow does occur throughout the area. The Tertiary volcanic rock then represents the aquifer in the area and has highly variable hydraulic conductivity depending on the fracture orientation, fracture spacing, and the openness of the fracture system below the water table.

Hydrothermal Alteration ("Scar") Aquitard: The hydrothermal scars scattered across the ridges above the mined area are composed of pyrite, clay, quartz, and carbonates altered to iron oxide, gypsum, jarosite, plus residual quartz and clay resulting from near-surface oxidation processes. These masses of altered material may principally be located above the natural water table, but they likely have very low hydraulic conductivity and serve to retard infiltration to the fractured aquifer system. Several 90-foot deep boreholes drilled by Molycorp into the "scar" material were either dry or produced over time very small flows (on the order of less than 1 gpm). Because masses of fractured rock are located within the hydrothermal "scars," some of this flow may have been from local perched zones. Where the altered material extends below the water table, the altered rock might locally create semi-confined conditions.

3.2 Ground-Water Recharge

River accretion studies by the U.S. Geological Survey (base flow measurements in late Fall 1965 and 1988) were referenced by Smolka and Tague (1988) of the New Mexico Health and Environment Department and in unpublished data by Vail (1989). Vail used the USGS data to calculate accretion for the Red River at nine locations from the Zwergle Dam site a few miles upstream from the Town of Red River to the Bear Canyon area. The segment of the Red River from the Molycorp Mill downstream to Bear Canyon (near the Questa Ranger Station) shows an accretion of 6.6 cubic feet per second (cfs). Of this, 5.0 cfs comes from Columbine Creek, which leaves 1.6 cfs related to recharge from seeps and springs along both sides of the river. These discharges at or close to river level are believed to be ground-water discharge and indicate that the Red River is a gaining stream (is recharged in part by ground water).

The 1.6 cfs accretion could be divided equally between the north and south sides of the river (0.8 cfs each). The more recent dewatering of the underground mine located beneath Goat Hill Gulch produced about 250 gpm (0.55 cfs). Thus, the mine dewatering removed about 69 percent of the total ground-water recharge (0.8 cfs) available to this segment of the river. According to Smolka and Tague (1988), over the 24-year period (between 1965 and 1988) of the USGS accretion study, there was a slight but insignificant increase in accretion along the Red River. These accretion studies were made over the same period of time that the mine was dewatering and, therefore, it appears that the decline in water level across the mined area did not impact the river (did not reduce accretion to the river).

3.3 Discussion of Ground-Water Recharge Issues

The issues concerning ground-water recharge to the Red River are:

1. The fracture system in the mineralized zone north of the river may be fairly well sealed (vein and fault zone mineralization). This could cause a low hydraulic conductivity condition within the mineralized zone and, during dewatering, a steep-sided depression in the water table may have been the result. A ground-water divide likely developed within the 800 to 1000 feet between the underground mine and the river.

2. If mine dewatering removed 0.55 cfs from storage beneath the mined area, how was accretion maintained in the segment of the Red River adjacent to the mine?

The mine waste dumps that cover fractured bedrock between the mill and the mine office were largely derived from the open-pit operation and, therefore, were in place prior to the deeper underground workings. These dumps are composed of non-mineralized, weakly-altered overburden and are not a source of acidic, metal-enriched water. Because these dumps may have higher rates of infiltration and store large amounts of water, these areas may be a source of recharge to the ground-water system adjacent to the river. Such a local increase in recharge could have offset some portion of the losses in stored water due to the mine dewatering. Mine waste dumps at higher elevations may have increased the surface discharge to the river as a further offset to accretionary losses due to dewatering, but much of this water is currently discharged to the caved area on Goat Hill Gulch.

It is also possible that the recharge to the river is not evenly divided between the two sides of the river. A Maxey and Eakin (1949) approach to drainage basin recharge, based on studies of ground-water basins throughout Nevada, estimates that 25 percent of the annual precipitation over the drainage area above all of the mine workings (i.e., open-pit and all underground workings) could contribute to recharge. Schilling (1956) indicates that the annual precipitation is about 21 inches. Twenty-five percent of the annual precipitation corresponds to 5.25 inches which, if distributed across the drainage area, is equal to 1.45 cfs. Although this would reduce the percentage of recharge captured by the mine, the volume of water needed to balance recharge lost to the mine during dewatering would not change (the 0.55 cfs would still have to be replaced to maintain accretion to the river). Bedrock beneath the drainage area on the south side of the river is part of the aquitard (e.g., Precambrian metamorphics and intrusive rocks) and may supply a lesser amount of ground-water recharge to the Red River.

The river bed is on or not far above the hydrogeological basement, and a significant volume of ground-water recharge from these crystalline rocks is not likely. However geologic cross-sections show several north-dipping, low-angle faults within the overlying volcanics that intersect the Red River at or close to river level. If these fractures were open and there was sufficient gradient, these might be an additional avenue for recharge to reach the river.

3.4 Water-Table Configuration

Based on Molycorp data, dewatering inflow for the older underground workings and for the open pit ranged from 15 to 30 gpm. These are very low flow rates. If these areas were below the water table, such rates could only be explained by very tight rock conditions in which virtually all the fractures were sealed. Schilling (1956) and Rehrig (1969) descriptions of the fracture systems and field examination of rock exposures in the same area indicate that open fractures exist (some fracturing can be related to mine activities). It is more likely that these low flow rates can be attributed to perched fracture water above a regional water table. The deeper underground workings dewatered at 250 gpm, which is also quite low. For comparison, Newmont's Gold Quarry Mine in Nevada is in fractured sedimentary rock and dewaters at 50,000 gpm (Carillo, 1993). However, if the fractures in the mineralized zone were largely sealed by mineralization/clay gouge, then 250 gpm, even below the water table, would not be unreasonable. It is possible that the open pit and most of the older underground workings near Sulphur Gulch (down to 7800 to 7900 feet) were above the regional water table and that the inflows were from perched fracture water. Currently, this inflow from the open pit and the older underground mine drains though a borehole into the deeper mine workings.

If the gaining stream model is used with the "normal" (versus the "acute") contour configurations (Appendix A) and with the dewatering data, it appears that the "normal" contour surface (Figure 6) would allow for most of the old workings and the pit to be relatively dry and above the regional water table. The Moly Tunnel (7960 adit) would be right at the water table at an elevation of 8000 feet. Construction of the 7960 adit did not produce much water, and therefore, the 8000-foot water-level contour might have curved more to the north. The "normal" water-table surface would have a southwesterly gradient of 0.036 foot/foot in this very simplified configuration. In contrast, the "acute" water table configuration would place most of the old workings and part of the open pit below the pre-mine water table.

We can use the simplified "normal" water-table surface to estimate the elevation of the water table in various areas of the underground workings. For example, the water level would continue to rise in the caved area above the underground workings in the Goat Hill Gulch area to an elevation of approximately 7840 feet. At Shaft No. 1, the elevation would be about 7820 feet and at Shaft No. 2, it would be closer to 7850 feet. With respect to the old Moly Tunnel (7960 adit), a conservative position would place it just below the water table at about 8000 feet.

Another element in the water-table surface configuration is the additional recharge from seepage barriers to the mine through the caved area. This currently amounts to about 70 gpm captured by the seepage barriers constructed on Capulin and Goat Hill Gulches. An additional 30 gpm drains from the open pit through a borehole in the old underground mine to the deeper workings. These seepage water amounts are occasionally augmented by surface water related to storm discharge. How much of this water actually reaches the caved area is unknown since it is a surface discharge and a certain amount must be lost to evaporation or infiltration to the vadose zone. (In the vadose zone, the water would be bound by surface tension in intergranular voids or micro-fractures.) It is possible that the additional recharge might cause some mounding of the water table surface, particularly in the caved area, and locally a slightly steeper gradient.

3.5 Rate of Rise for the Water Table

The water level in the mine workings is currently at 7370 feet (5/21/93). According to Molycorp records, the caved area began to fill by October 20, 1992. Using the elevation of the bottom of the caved area (7226 feet) and the time since filling began (183 days), the rate of rewatering is 0.78 foot/day. (Over time, the rate of rise will change as a balance between less available space to fill [increases the rate] and the decline in gradient driving the water into the mine workings as the original water-table depression flattens out [decreases the rate].) However, if we use 0.78 foot/day as the rate, it would take 1.16 years for the water level to rise to the downgradient elevation (7700 feet) of the Red River (this assumes a southwestern gradient based on the normal contour configuration in the caved area at Goat Hill Gulch (Figure 7). In other words, after 1.16 years (from May, 1993), there would be a slight gradient from the cave area toward the river. Using the same rate of 0.78 feet/day, it would take 1.65 years to reach the postulated water-table elevation of 7840 feet in the caved area. In the case of the Moly tunnel (7960 feet), it would require 2.21 years for the water level to reach 8000 feet and begin to flow down to the adit.

3.6 Water Chemistry In and Near the Mined Area

Table 1 compares the water chemistry from the seepage barrier system (in the upper parts of Capulin and Goat Hill Gulches), the underground mine (shaft No. 1), the Red River above the mined area, and two production wells. Chemistry for this table is derived from unpublished Molycorp data and from Vail (1989, 1993). All concentrations are expressed in milligrams per liter (mg/L).

TABLE I Chemistry of Seepage Barrier, Mine and Red River Water *(in mg/L)*					
	Seepage Barrier Water	**Mine Water**	**Red River Sewage Plant Well**	**Columbine Well No. 2**	**Red River**
pH	2.8	7.2	3.96	5.9	7.6
Aluminum	979.0	1.0	25.2	--	<0.5
Sulphate	13,043	985	776	536	86
TDS	20,760	2,738	1,034	848	200
Fluoride	45.4	6.0	2.13	2.0	0.32
Cadmium	0.47	<0.005	<0.005	<0.01	<0.005
Lead	<0.1	<0.1	<0.1	<0.05	<0.1
Iron	562.2	1.14	27	<0.05	0.467
Manganese	554.4	2.70	5.0	0.01	0.179
Zinc	142.6	0.54	1.9	0.69	0.041
Copper	13.3	<0.01	0.051	<0.01	0.012

The seepage barrier waters reflect the chemistry of the leachate generated by oxidizing waters infiltrating the Mine Waste dumps above Capulin and Goat Hill Gulches.

The mine waters are significantly more alkaline (higher pH), but lower in metals, sulphate, and TDS compared to seepage water. The high sulphate in the mine water suggests that oxidizing surface waters are reacting with the pyrite in the mineralized zone to produce both dissolved sulphate and iron. The alkalinity of the mine water is significant because the lowest solubility of dissolved aluminum is in the pH range of 6 to 7 (Drever, 1982). In this pH range, aluminum concentrations of approximately 1.0 mg/L and above would lead to precipitation of gibbsite (aluminum hydroxide). This suggests that the mine water will act as a sink for any aluminum brought in from seepage waters.

In several respects the mine water is of higher quality than the water from near-by production wells located outside the mined area. The pH for the Columbine and Red River wells

(Table 1) is acidic, considerably lower than the more alkaline mine water. Aluminum and iron concentrations in the Red River well are significantly above mine water concentrations. Manganese, zinc and copper are higher in the Red River well and copper is higher in the Columbine well. The mine water does contain higher levels of sulphate and TDS than either well. The mine water has about the same pH as the Red River water sample, but concentrations are higher for the remaining constituents.

Schilling (1956) mapped limonite (iron oxide) cemented alluvial and mudflow deposits flanking some of the drainages across the mined area. These Quaternary age deposits represent evidence for acidic, metal-bearing surface and near-surface recharge water in the area long before mining began.

Figure 7 illustrates the relationship between the deep underground mine including the caved area, the postulated water table surface, and the Red River. The underground mine would be on the order of 530 feet below the water table and 390 feet below river level. For the deep mine water to impact the Red River, there would have to be sufficient head to move the ground water upward principally along preferred pathways. These pathways could consist of the low-angle northward- and westward-dipping faults and north-south high-angle faults that intersect the mine workings. Based on the lack of impact on the Red River by the mine dewatering, these structures do not appear to be efficient conduits between the mine and the river.

The most likely source of mine-affected ground water is from the upper part of the caved area. There are two reasons for this area being a source of higher sulfate/TDS water:

- The broken rock (with a greater surface area) in the cave area is more reactive to oxygenated ground water than the fractured bedrock, and
- Seepage barrier water from Capulin and Goat Hill Gulch mine waste dumps is discharged to the caved area.

3.7 Ground-Water Transport

The mine workings are in a mineralized zone where fractures and faults are completely, or at least partially, sealed by mineral deposits, clay gouge, and intrusive material in the form of dikes. The structural trend of the mineralized zone is east to northeast, roughly normal to the postulated water-table elevation contours, or parallel to the southwesterly flow direction. If these fractures were open to any great extent, then they would be a significant pathway for recharge to the Red River. The lack of any known impact of the mine dewatering on accretion to the Red River suggests that there is a poor hydraulic connection between the east-trending structures and the river. Based on Molycorp maps, some north-trending, high-angle faults intersect the mineralized zone and extend to the river. Where such faults were cut by the mine workings, in some cases, inflows of ground water occurred (no measured discharge data are available). If ground water that is influenced by the mine water reaches the river, it would more likely be along a few preferential pathways related to the north-trending high-angle faults and/or the low-angle north-dipping faults that intersect the surface near the river. Mapping of springs and seeps along the river combined with rock units and structure as well as water chemistry would help to identify potential pathways.

With the currently available information, it is not possible to make meaningful quantitative estimates for the velocity of ground water through the fractured bedrock. Tracer tests in sets of nearby boreholes would probably allow the best estimate of fracture-related, ground-water velocity. These tests need to be well planned in terms of distances between boreholes and their relationship to mapped fractured systems.

Seepage velocity formulas are based on advection in granular material, not fractured rock. Using the caved area (located on Goat Hill Gulch) above the deep underground workings as a source and published values for hydraulic conductivity and porosity for fractured rock (Freeze and Cherry, 1979), rough estimates of travel time from the mine to the river can be made. According to Freeze and Cherry (1979), the range of hydraulic conductivity for fractured igneous and metamorphic rocks is 10^{-1} to 10^{3} gallons/day/ft^2 and for permeable basalt 1 to 10^5 gallons/day/ft^2. The porosity range for fractured crystalline rock is 0 to 10%, and for fractured basalt 5 to 50%.

The seepage velocity formula is:

$$V = \frac{KI}{7.5n_e}$$

where: V = seepage velocity, in feet/day
K = hydraulic conductivity, in gallons/day/square foot
I = hydraulic gradient, in feet/feet
n_e = porosity,a percent.

$$\textit{Travel Time} = \frac{\textit{Distance from Source to River}}{\textit{Velocity}}$$

The hydraulic gradient (0.036 foot/foot) and the down-gradient distance to the river from the caved area (3500 feet) are based on the "normal" water-table configuration map (Figure 6). Seepage velocity was estimated by using a hydraulic conductivity equal to 10 gallons/day/ft^2 and a porosity of 10%. These values are in the mid- to upper range of values for fractured igneous and metamorphic rocks and in the lower range for permeable basalt. The resulting seepage velocity is 0.48 foot/day and the travel time from the caved area to the river is 19.97 years. High-angle faults that cut across the structure of the mineralized zone and the low-angle north- and west-dipping faults may represent preferential pathways for flow to the river at rates less than the calculation indicates. However, without field data based on tracer tests applied to the local fracture system, estimates of seepage velocity and travel time calculated from formulas *derived from granular or matrix flow* are likely to be in significant error.

Another approach to estimating hydraulic conductivity and travel time is to use the dewatering rate for the mine, 0.55 cfs, as the quantity of water that could be available for recharge to the river from the underground mine area. Using the equation for discharge:

$$Q = KAI$$

where Q = discharge (recharge to river), in gallons/day
K = hydraulic conductivity, in gallons/day/square foot
A = cross-sectional area, in square feet
I = hydraulic gradient,in feet/feet,

it is possible to estimate K. To calculate a cross-sectional area, it is assumed that the springs just above river level and any water that moves up along low-angle faults beneath the river bed would be within a zone of about 50 feet in thickness and that the length of the recharge zone down gradient of the mined area is about 6000 feet.

Q = 355,449.6 gallons/day (equals 0.55 cfs)
A = 300,000 $feet^2$
I = 0.036 foot/foot

The calculation gives an estimated hydraulic conductivity (K) of 33 $gallons/day/ft^2$. If the estimated value for K is substituted in the seepage velocity formula, the resulting velocity is 1.58 feet/day. The higher K value results in a travel time of 6.06 years from the caved area to the river.

In summary, the two different approaches to travel time indicate that mine water in the caved area, after the water table stabilizes, could reach the river in a time period ranging from 6.06 to 19.97 years. It would take about 6 months (using 0.78 foot/day rate) for the water level to rise from the projected river level to the water-table surface in the caved area (Figure 7). Although there would be gradients toward the river during this period of time, given the travel time estimates at maximum gradient (e.g., at the stable water table), this period is too short to be used in estimating when mine-related water could reach the river. If the time to reach the stable water table (1.58 years) is added to the above figures, it would take from 7.64 to 21.55 years for mine water to reach the river from the position of the caved area.

4.0 RECOMMENDATIONS

There are at least three approaches to controlling the flow of ground water from a mined area to a gaining river:

- gradient control through a pumping or dewatering program;
- chemical precipitation of metals and sulphate; and
- grout sealing of preferential pathways.

Gradient Control: For gradient control, pumping (from the shaft and/or decline facility) partially dewaters the mined area. The effect of the dewatering is to create a gradient away from the Red River preventing mine waters from influencing the recharge. The Questa Mine is on standby status and, depending on improving economic conditions, the underground mine would be reactivated. Dewatering of the mine to resume operations would prevent mine water, including that in the caved area, from reaching the river.

At some future date, when the ore reserves are exhausted, a pumping program for gradient control can be implemented. Initially, the gradient reversal created by the pumping program would focus on developing a water table depression across the caved area such that the water level elevation was at least just below the projected river level (Figure 7). This condition could likely be accomplished at pumping rates below those required to dewater the mine (250 gpm). Pumping at Shaft No. 1 or No. 2 at underground mine depths (7100 to 7300 feet) should withdraw enough water to reduce the water level in the caved area to below the projected river level elevation. The rate of decline of the water level and the water-level elevation could be monitored at the decline or at a non-pumping shaft as is presently done. The deeper mine workings would not have to be dewatered in this initial effort. Dewatering for gradient control will place the Moly tunnel (7960 adit) above the water table. The tunnel has a cement plug such that fracture water (draining from higher levels and not drained to the deep mine) does not access the river.

The rate of rise, as well as the elevation of the water level in the mine area, are currently being monitored. Both should continue to be monitored on a monthly basis to aid in verifying conclusions in this report regarding the time to reach a stable water-table surface. The monthly monitoring data will be used to evaluate seasonal and any longer term changes in the rate of rise of water-level that might shorten or lengthen the time before the initiation of a pumping program.

A conservative position for initiating a pumping program to control the gradient across the caved area would be 4 years (October 1996) from the date when the water began to rise in the caved structure (October 1992). This would allow some time to adjust pumping rates to develop the appropriate water-table depression. This position is conservative to allow for variations in the travel time approximations and to recognize the potential for structures with down-gradient orientations to conduct ground water at higher rates than the surrounding rock. Variations in travel time calculations result from: (1) lack of site-specific hydraulic conductivity values, and (2) the possibility that the water-table surface may slope more directly toward the river with a steeper gradient and a shorter travel time. However, the "normal" water table configuration, for reasons already discussed, is believed to be not far off from the true surface.

Water withdrawn from the mine area, based on the chemistry in Table 1, would need to be discharged to the tailings pond facility near Questa.

Chemical Precipitation and Grout Sealing: Sealing of open fractures by chemical precipitation or grouting methods faces a formidable problem because of the large number of low-and high-angle fractures throughout the area. To find and seal all of the potential recharge pathways and to develop a monitoring program that can detect shifts from sealed to open fractures is not a feasible option at this site.

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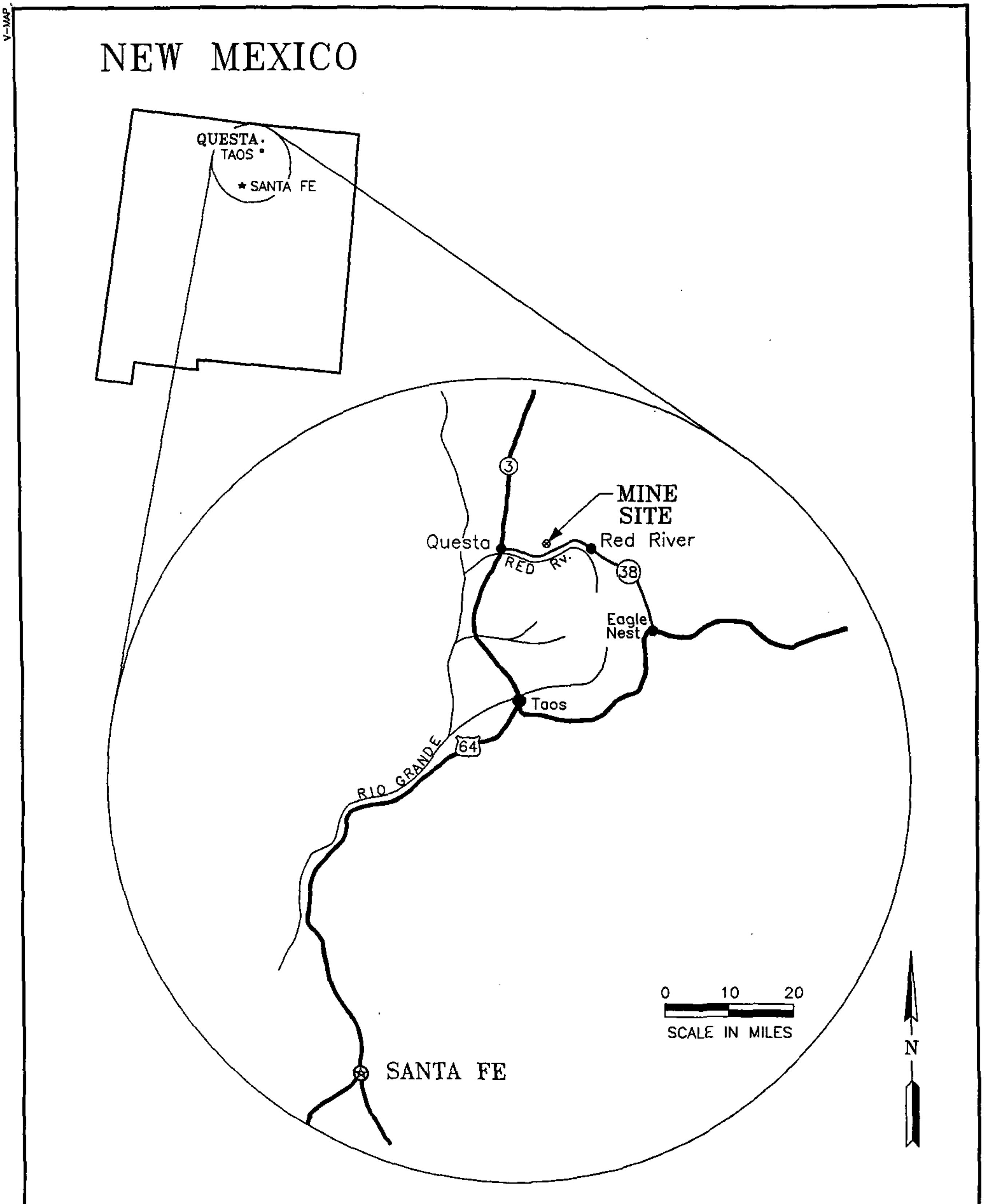
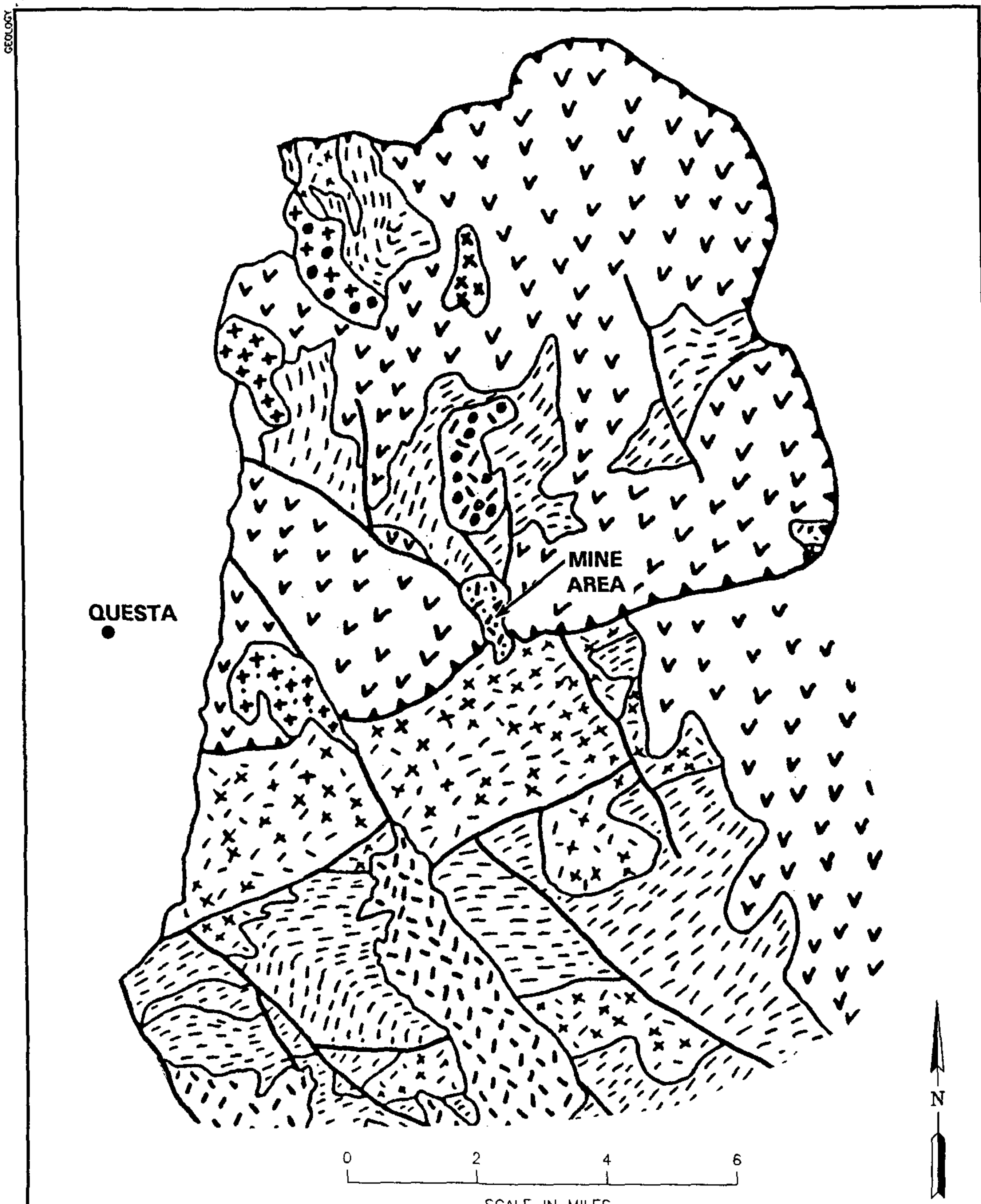


The GeoWest Group Inc.				LOCATION MAP Molycorp, Inc. Questa, New Mexico	FIGURE: 1
PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.		



REFERENCE: MOLYCORP FILES.

SOUTH PASS RESOURCES, Inc.				GENERALIZED GEOLOGIC MAP Molycorp, Inc. Questa, New Mexico	FIGURE: 2
PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.		

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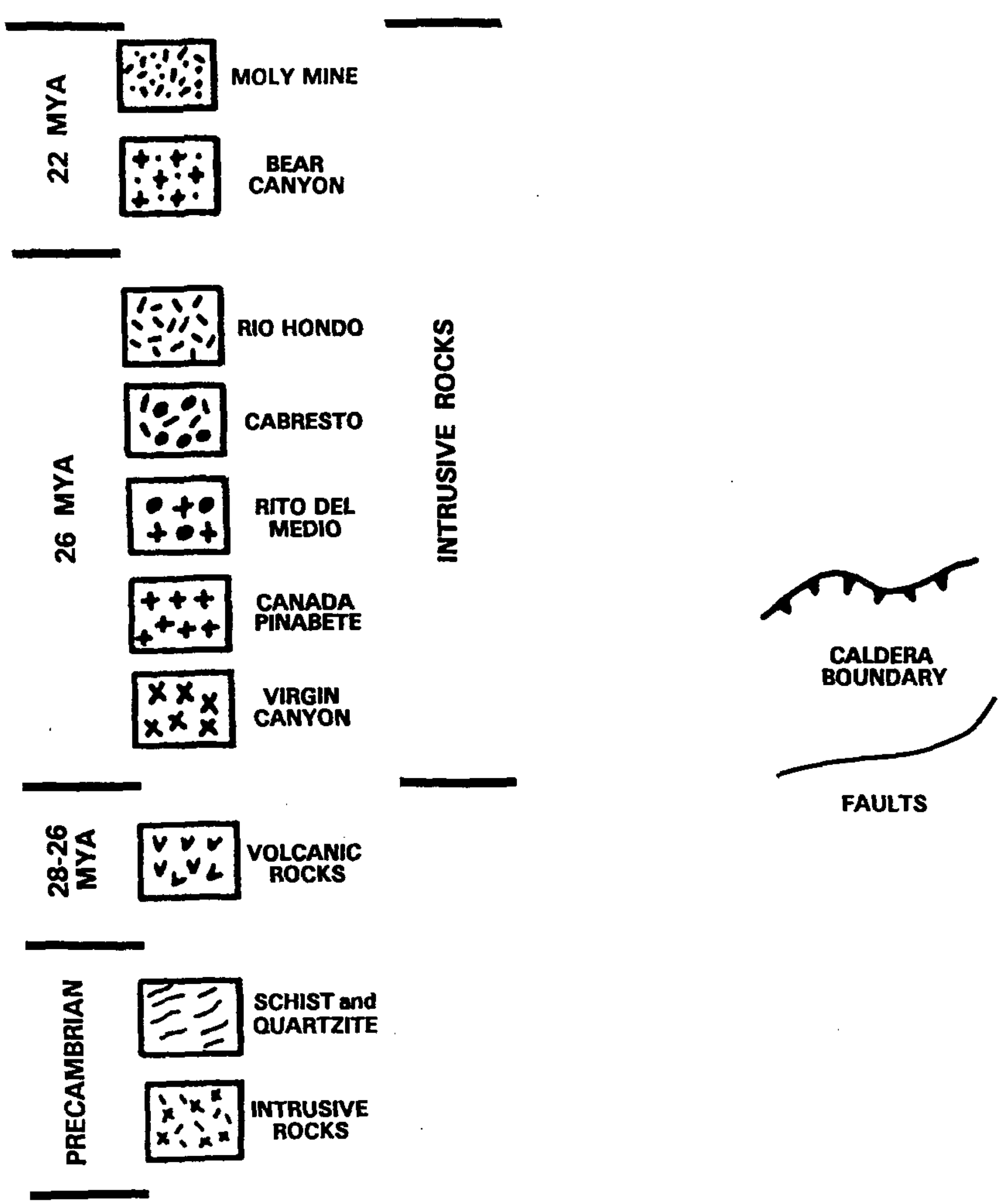

REFERENCE: MOLYCORP FILES.

SOUTH PASS RESOURCES, Inc.				GENERALIZED GEOLOGIC MAP KEY Molycorp, Inc. Questa, New Mexico	FIGURE: 2a
PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: ACK	DRAWN BY: M.O'M.		

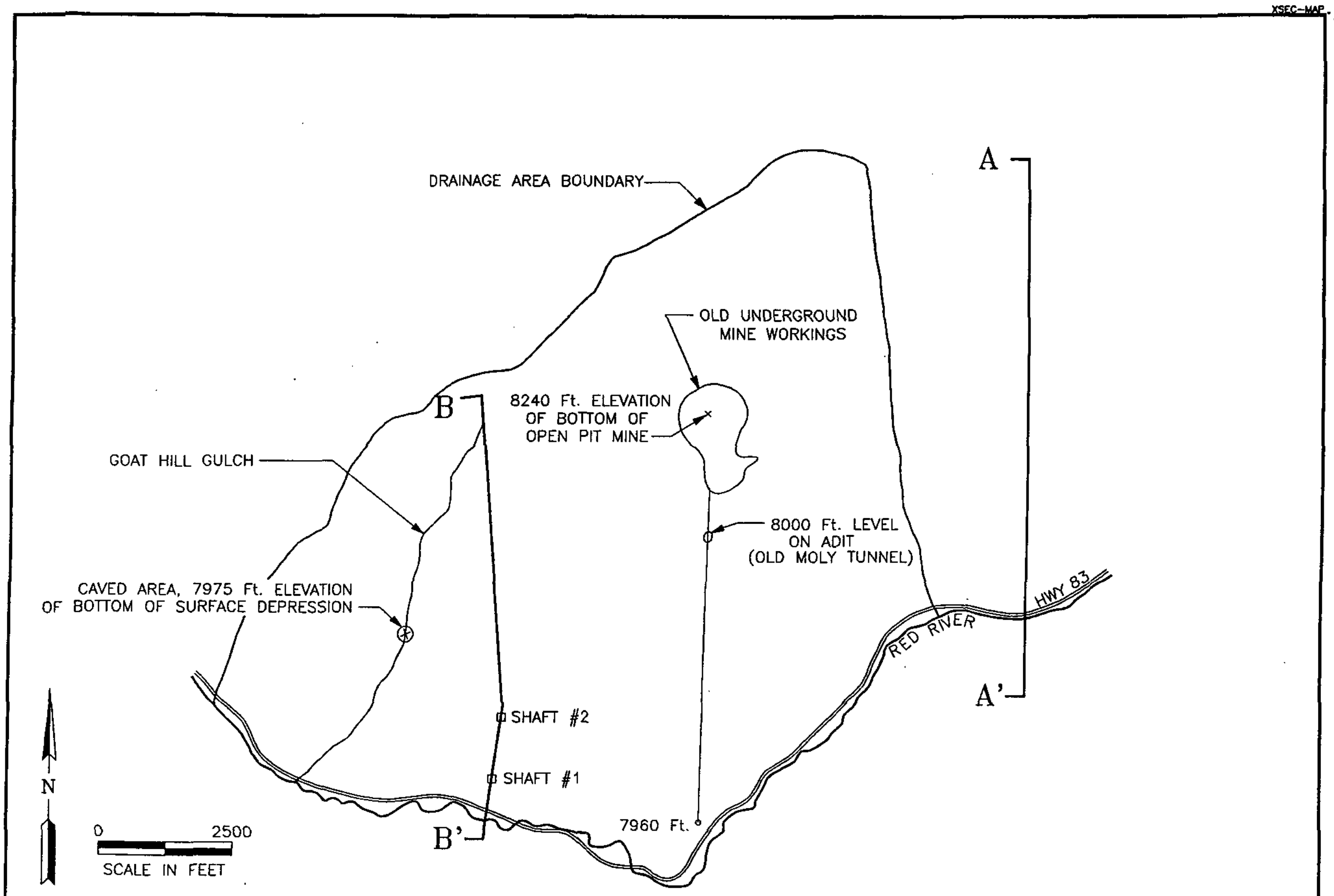

FIGURE: 3	The GeoWest Group Inc.				APPROXIMATE CROSS SECTION LOCATIONS Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.	

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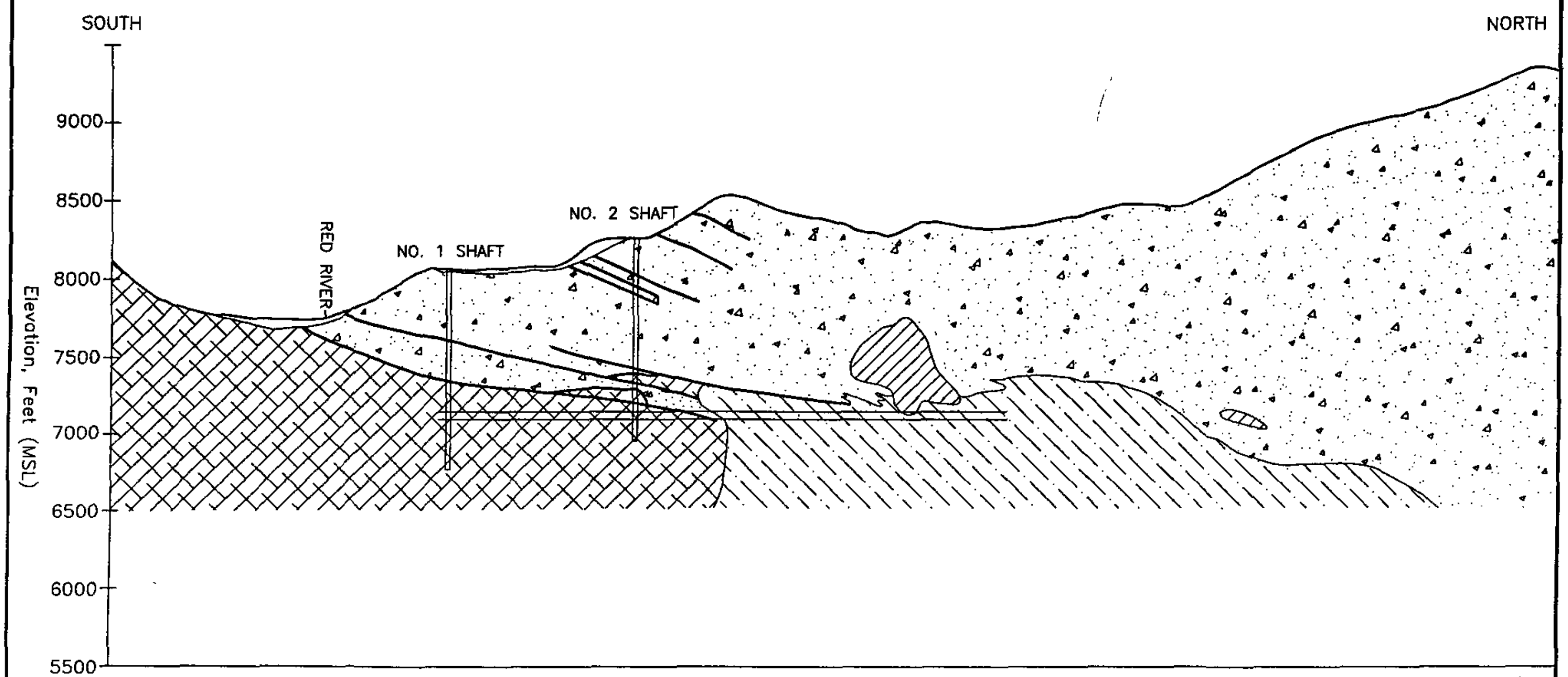
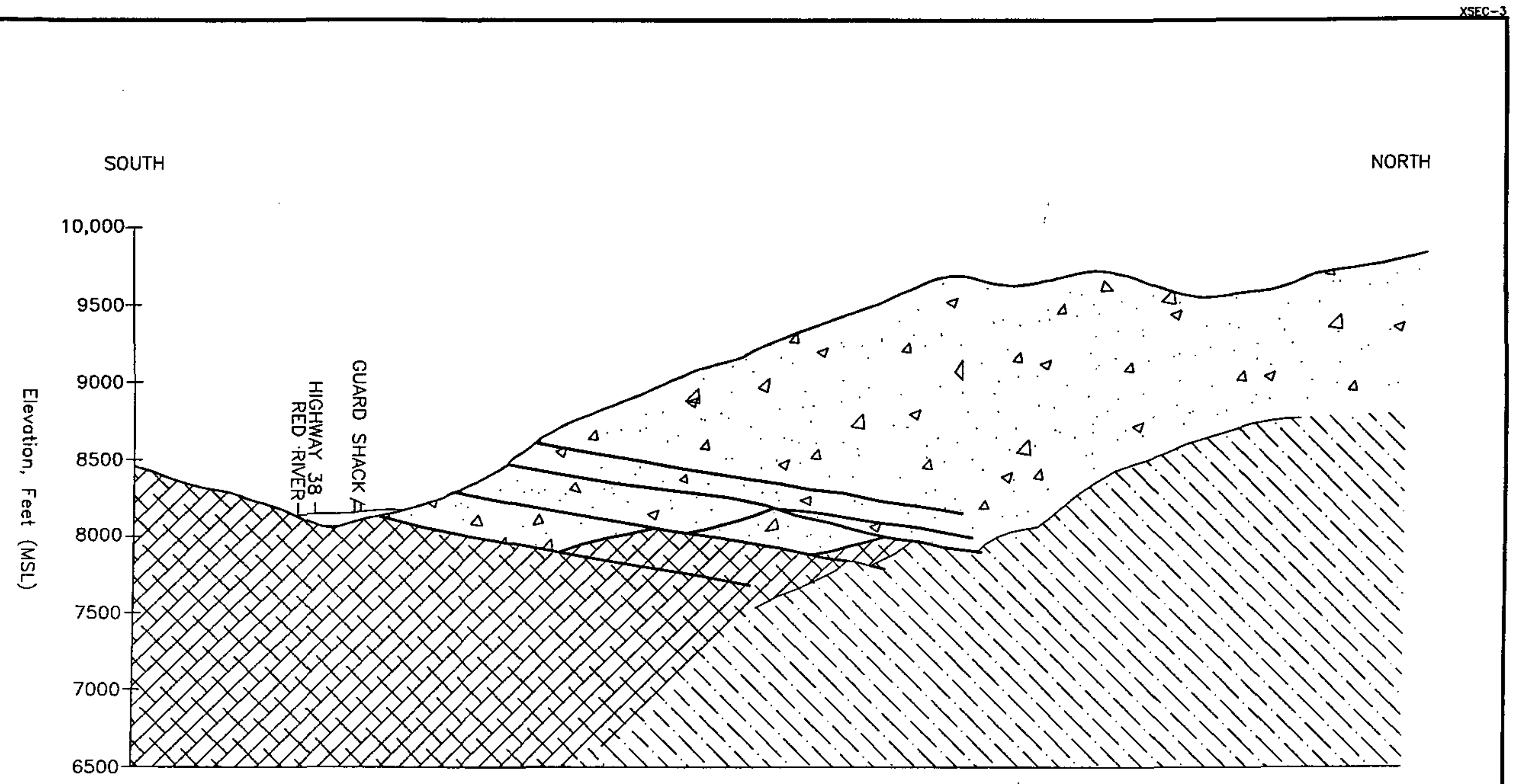


LEGEND

- MINERALIZED ZONES
- TERTIARY INTRUSIVE: MINE APLITE AND GRANITE
- TERTIARY VOLCANICS: FLOWS, TUFFS, DIKES
- PRECAMBRIAN ROCKS
- LOW-ANGLE NORTH-DIPPING FAULTS

VERTICAL & HORIZONTAL SCALE
1Inch = 1000 Feet

FIGURE: 4	The GeoWest Group Inc.				CROSS SECTION B – B' Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.	



LEGEND

TERTIARY INTRUSIVE: MINE APLITE AND GRANITE

TERTIARY VOLCANICS: FLOWS, TUFFS, DIKES

PRECAMBRIAN ROCKS

LOW-ANGLE NORTH-DIPPING FAULTS

VERTICAL & HORIZONTAL SCALE
1 Inch = 1000 Feet

FIGURE: 5	The GeoWest Group Inc.				CROSS SECTION A – A' Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.	

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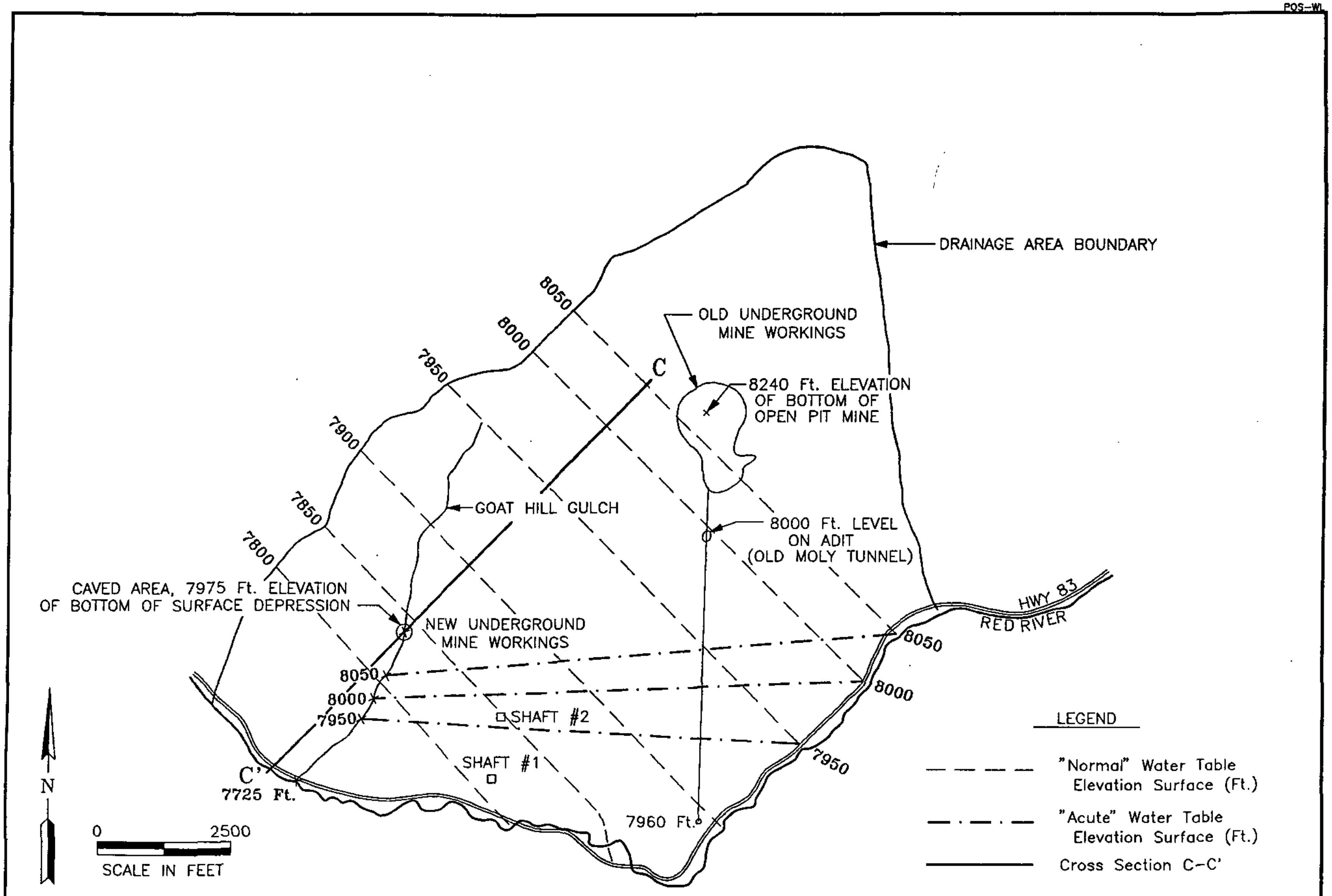

FIGURE: 6	The GeoWest Group Inc.				POSTULATED WATER–LEVEL ELEVATION SURFACES Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001–02	DATE: 7–14–93	AUTHOR: JCK	DRAWN BY: M.O'M.	

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RELATIONSHIP BETWEEN UNDERGROUND MINED AREA, POSTULATED WATER TABLE AND RED RIVER

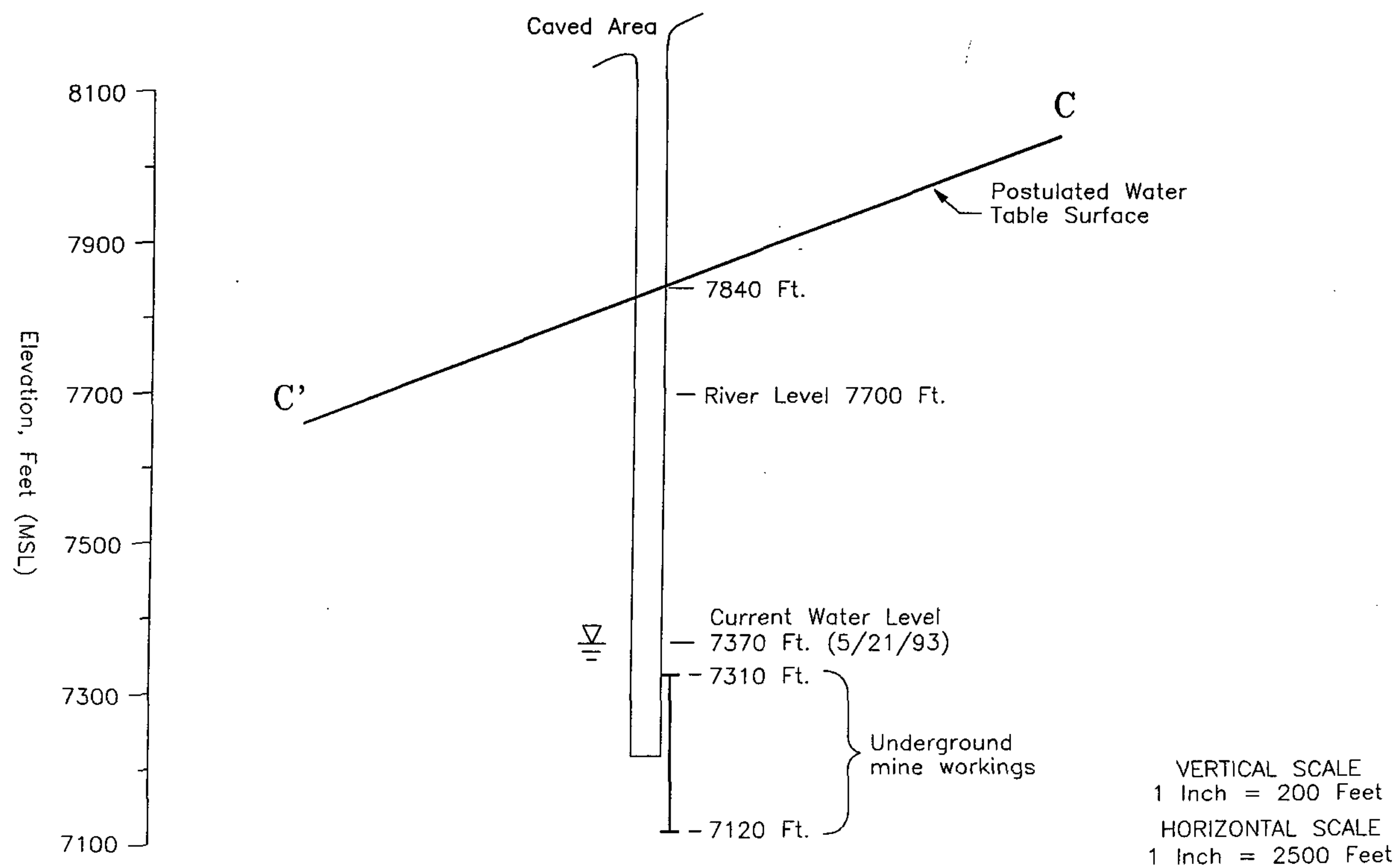

FIGURE: 7	The GeoWest Group Inc.				CROSS SECTION OF CAVED AREA Molycorp, Inc. Questa, New Mexico
	PROJECT No.: 001-02	DATE: 7-8-93	AUTHOR: JCK	DRAWN BY: M.O'M.	

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APPENDIX A

WATER-TABLE CONFIGURATION

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WATER-TABLE CONFIGURATION

The accretion studies were made under base flow conditions which means, because accretion occurs along the entire stretch of the Red River included in the study, ground water flows directly to the river. Therefore, the river can be classified as a gaining stream. Where water-level elevation contours cross a gaining stream, the contours point or "V" in an up stream direction. This is because the river as the lowest topographic element in the drainage basin intersects the water table resulting in any particular contour extending from that point on the river in a downstream direction, but flaring out at some angle beneath the floodplain or bedrock valley walls in this case.

There are limiting angular positions for these contours with respect to the river channel. These positions range from a contour normal to the river channel (i.e., "normal contour pattern") to an acute angle configuration in which the contours are nearly parallel to the channel and the acute angle points up stream (i.e.,"acute contour pattern") as illustrated in Figure A-1. One elevation for any of these contours is fixed by elevations along the river channel.

The "normal" configuration was drawn by simply extending a series of parallel contours from their respective elevations along the river. The "acute"pattern was drawn by connecting the appropriate elevation of the Red River with a corresponding elevation on the deepest and farthest down gradient tributary gulch (Goat Hill Gulch) in the mine drainage area. This represents an extreme configuration because, if it existed, there would be natural springs along the bottom of the gulch wherever the water table was intersected.

The absence of such springs indicates the water table is deeper than the bottom of Goat Hill Gulch, but for the purpose of indicating a maximum condition this configuration will be used. To test these two extreme configurations water level contours can be evaluated based on existing information on water levels drawn in this case from dewatering information associated with the mining operations.

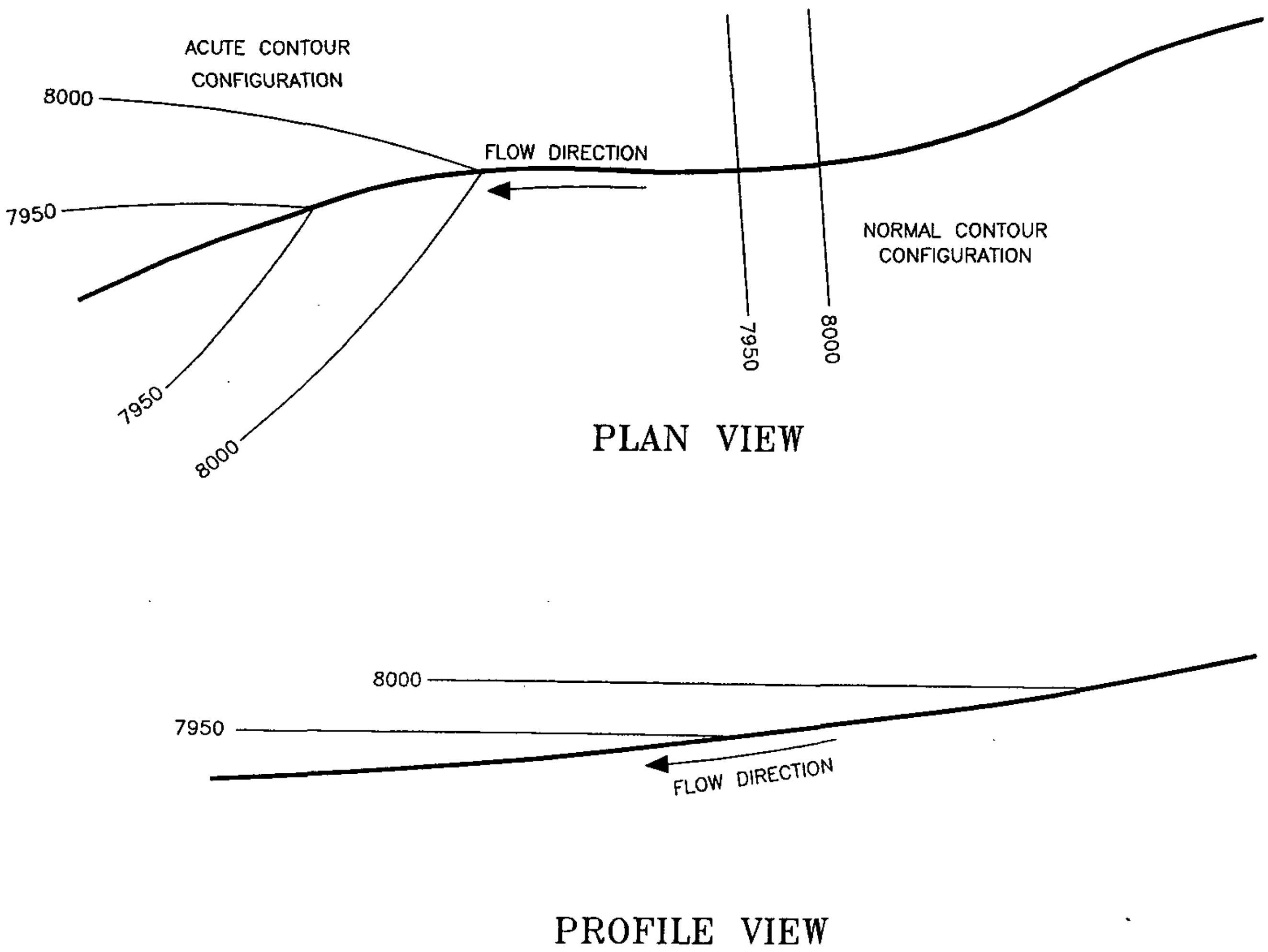

FIGURE: A1	The GeoWest Group Inc.				LIMITING CONFIGURATIONS FOR A GAINING STREAM
	PROJECT No.: 001-02	DATE: 7-14-93	AUTHOR: JCK	DRAWN BY: M.O'M.	Molycorp, Inc. Questa, New Mexico